10/591412

IAP5 Rec'd PCT/PTO 01 SEP 2006

VERIFICATION OF TRANSLATION

I, the undersigned, hereby declare:

That my name and address are as stated below under my signature;

That I am conversant with the English and German languages; and

That the attached translation is a true translation prepared by me of the accompanying International Application No. PCT/EP2004/050236, filed on March 2, 2004, and of the accompanying amended pages filed on June 25, 2005, and on September 5, 2005, respectively.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any U.S. patent issued thereon.

August 3, 2006

Ann Kistler Long

(signature)
Ann Kistler Long
Niesenweg 65
CH-3125 Toffen
Switzerland

10/591412

IAP5 Rec'd PCT/PTO 01 SEP 2006

X-ray Tube for High Dose Rates, Method of Generating High Dose Rates with X-ray Tubes and a Method of Producing Corresponding X-ray Devices

This invention relates to an X-ray tube for high dose rates, a corresponding method for generating high dose rates with X-ray tubes as well as a method of producing corresponding X-ray devices, in which an anode and a cathode are disposed situated opposite each other in a vacuumized inner space, electrons being accelerated to the anode by means of impressible high voltage.

Recently a lot of time and effort of industry and technology has been directed toward improving the efficiency of irradiation systems. Irradiation systems find application not only in medicine, e.g. in diagnostic systems or with therapeutic systems for irradiation of diseased tissue, but are also employed e.g. for sterilization of substances such as blood or foodstuffs, or for sterilization (making infertile) of creatures such as insects. Other areas of application are to be further found in classical X-ray technology such as e.g. x-raying pieces of luggage and/or transport containers, or non-destructive testing of workpieces, e.g. concrete reinforcements, etc. Thus diverse methods and devices have been developed for γ-ray systems or X-ray systems in order to obtain a higher percentage of usable X-rays from the gamma emitters. This means that a multitude of systems have been developed in the attempt to increase the percentage of energy converted into γ-rays, which can then really be used for irradiation. Also attempted in the same way through newly developed systems and methods has been to obtain a more uniform distribution of the γ-rays over the surfaces to be irradiated. With all systems and methods, in particular with those using e.g. ^{60}Co or ^{137}Cs as gamma emitters, great efforts have been made furthermore to obtain a more uniform irradiation over various depths of the irradiated material. In the state of the art, the absorbed energy distribution for a particular substance depends upon a multitude of parameters, in particular upon the material irradiated, the distance from the radiation source to the irradiated substance, and the geometry of the irradiation method.

X-ray tubes having the required capacities usually comprise in the state of the art an anode and a cathode which are disposed opposite each other in a vacuumized internal chamber and which are enclosed by a cylindrical metal part. Anode and/or cathode are thereby electrically insulated by means of an annular ceramic insulator, the ceramic insulator or insulators being disposed behind the anode and/or cathode, axially to the metal cylinder, and closing the vacuum chamber at the respective end. In the middle of their disk, the ceramic insulators have an opening in which a high voltage supply, the anode or the cathode are installed vacuum-tightly. This type of X-ray tube is also referred to as a bipolar X-ray tube in the state of the art.

A conventional X-ray emitter according to the state of the art is reproduced e.g. in Figure 1. An electron beam is thereby generated from an electron emitter, as a rule a tungsten coil, and is accelerated to a target by means of an applied high voltage. Anode (target) and cathode are disposed opposite each other in a vacuumized internal chamber, and are normally enclosed by a cylindrical metal part. Anode and/or cathode are thereby electrically insulated by means of an annular ceramic insulator, the ceramic insulator or insulators being disposed behind the anode and/or cathode, axially to the metal cylinder, and closing the vacuum chamber at the respective end. With impingement of the electrons on the target, X-ray radiation (γ-radiation) is thereby generated at the thus arising focal spot. The X-ray radiation emerges into the outer space through a window, and is used for irradiation purposes. This type of X-ray tube is also termed bipolar X-ray tube in the state of the art. Despite the efforts mentioned above, the drawbacks of the state of the art could not be overcome or could only be overcome insufficiently. Thus, for example, only a small portion of the radiation generated at the target reaches the material to be irradiated. For reasons of geometry, the major part of the radiation is absorbed in the tube itself. Depending upon the size of the object, a particular irradiation spacing must be chosen in order to irradiate the object completely. Moreover the dose rate per surface element in such a configuration is determined by the distance of the object from the focal point of the tube and by the quantity of radiation that is generated at the focal point. This amount of radiation is limited, for its part, by the thermal energy which must be discharged through cooling of the focal point so that the material in the focal point does not

melt. The focal point is, as a rule, thereby clearly smaller than the object to be irradiated, i.e. the radiant flux density to be used decreases from the focal point to the object at approximately the square of the distance. For reasons of cooling technology, the radiation capacity of such radiation emitters is limited to a few kW, typically about 6 kW. Because of these two factors the specific dose rate of such a configuration is greatly limited.

It is an object of this invention to propose a new X-ray tube for high dose rates and a corresponding method for generating high dose rates with X-ray tubes which do not have the drawbacks described above. In particular, an X-ray emitter should be proposed which enables a dose rate many times higher than conventional X-ray emitters. Likewise the percentage of usable energy converted into γ-rays should be increased, and a more uniform distribution of the γ-rays with respect to the surface to be irradiated and the depth of the material should be obtained.

This object is achieved according to the invention in particular through the elements of the independent claims. Further advantageous embodiments follow moreover from the dependent claims and from the description.

In particular, these object are achieved according to the invention in that in the X-ray tube an anode and a cathode are disposed opposite each other in a vacuumized internal chamber, electrons being able to be accelerated to the anode by means of impressible high voltage, the cathode comprising a thin layer or coating of an electron-emitting material, and the cathode comprising a substrate substantially transparent for X-ray radiation. The cathode can thereby close the vacuumized internal chamber toward the outside, for example. For conversion of the electrons into X-ray radiation, the anode can comprise in particular e.g. gold and/or molybdenum and/or tungsten and/or a compound of the metals. An advantage of the invention is, among others, that the cooling of the anode can be optimized since the anode does not have to be selected to be transparent for X-ray radiation, compared with a design alternative with an anode transparent for X rays.

In an embodiment variant, the cathode comprises a thermionic emitter. This embodiment variant has the advantage, among others, that thermionic emitters are state of the art in X-ray tubes, and distinguish themselves through high stability and long service life. The emitters can thereby consist of heated tungsten wires which are either strung parallel or are welded to a mesh grid. Emitters of barium hexaboride or so-called heated dispenser cathodes based on barium mixed oxides can also be used, however, which have a very high emission current density, and can be arranged in groups in order to achieve large-area cathodes.

In another embodiment variant, the cathode comprises a cold emitter, in particular with metal tips and/or carbon tips and/or carbon nano tubes. This embodiment variant has the advantage, among others, that the emitters can be installed in a thin layer on a substrate in a large-area way, and can thereby result in little to no heat loss in operation. A cooling can thereby be omitted, and a high transmission for X-rays can be ensured for the cathode. These cold emitters are preferably combined with an extraction grid with which the current density can be controlled.

In another embodiment variant, the cathode comprises a substrate for the thermionic emitters or the cold emitters of a material especially penetrable for X rays, such as e.g. beryllium, aluminum or in particular pyrolytic graphite. The substrate can thereby be designed such that it serves at the same time as the closure of the vacuum vessel.

In an embodiment variant, the X-ray tube is designed as an anode hollow cylinder with a coaxial cathode hollow cylinder inside. This embodiment variant has the advantage, among others, that e.g. the material to be irradiated can be put inside the cathode hollow cylinder. This ensures an evenly high and homogenous irradiation of the object from all sides (4π), which would hardly be possible otherwise. This embodiment variant can be suitable in particular for sterilization with continuous conveyance of the material to be sterilized, and thus for high throughput.

In another embodiment variant, the anode is designed as a round or angular surface, the anode being irradiated by a cathode of laminar or reticulate design, substantially transparent for X-ray radiation (γ). This embodiment variant has the advantage, among others, that also large-surface material to be irradiated can be brought very close to the X-ray source. Since the anode does not need to be irradiated through, and a high cooling capacity on the anode can thereby be achieved, the current density of the emitter at the site of the material to be irradiated can be increased many times over, compared with an embodiment with transparent anode. Furthermore it is also possible with this embodiment variant to irradiate the material to be irradiated from a multiplicity of sides, in particular from 2 sides, at the same time, using a multiplicity of emitters, and thereby further reduce the required irradiation time. A multiplicity of such embodiment variants can be also be put together in modules in order to irradiate larger objects.

It should be stated here that, besides the method according to the invention, this invention also relates to a device for carrying out this method as well as to a method for producing such a device.

Embodiment variants of the present invention will be described in the following with reference to examples. The examples of the embodiments are illustrated by the following enclosed figures:

Figure 1 shows a block diagram illustrating schematically an X-ray tube 10 of the state of the art. Electrons e^- are thereby emitted from a cathode 20, and X-rays γ radiated from an anode 30 through a window 301.

Figure 2 shows a block diagram, illustrating schematically the architecture of one embodiment variant of an X-ray tube 11 according to the invention. Electrons e^- are thereby emitted by a transmission cathode 21, and X rays γ radiated from an anode 31, the cathode 21 forming the cylinder barrel of a cylindrical tube core, and closing the vacuumized internal chamber 41.

Figure 3 shows a block diagram, illustrating schematically the architecture of an embodiment variant of an X-ray tube 12 according to the

invention. Electrons e^- are thereby emitted from a transmission cathode 22, and X rays γ emitted from an anode 32, the cathode 32 closing the vacuumized internal chamber 42 toward the outside. The anode 32 is designed as a round or angular surface, and is irradiated by a transmission cathode 22 of laminar, reticulate, or linear form.

Figures 2/3 illustrate architectures as they can be used to achieve the invention. In these embodiment examples for an X-ray tube 11/12 with high dose rate, or respectively for a method for generating X rays with high dose rate, an anode 31/32 and a cathode 21/22 are disposed opposite each other in a vacuumized internal chamber 41/42. By means of impressible high voltage, electrons e^- are accelerated to the anode 31/32 through the vacuumized internal chamber 41/42. In other words, the electrons are focused by the cathode 21/22 on a large surface of the anode 31/32 or on the entire anode 31/32, and generate X-ray radiation γ there. The vacuumized internal chamber 41/42 can be enclosed e.g. by a metal housing 52, for instance a cylindrical metal housing. The metal housing 52 can have e.g. a minimal wall thickness of 2 mm. It is likewise conceivable for the metal housing 50/52 facing the vacuumized internal chamber 41/42 to be electropolished and/or mechanically polished. The anode 31/32 and/or the cathode 21/22 can be electrically insulated by means of an annular and/or discoidal insulator 62. The insulator can e.g. be composed substantially of an insulating ceramic material. Conceivable as ceramic material is e.g. ceramic material of at least 95 % Al_2O_3. Sintered on the ceramic can be a single or multiple layer of an alloy, for example. The alloy can comprise e.g. an MoMnNi alloy. Conceivable moreover is that the vacuumized internal chamber is enclosed by a ceramic housing, which at the same time insulates the cathode from the anode. The cathode 21/22 comprises a substrate substantially transparent for X-ray radiation γ. The cathode 21/22 can further comprise e.g. a thermionic cathode material (tungsten, tantalum, lanthanum hexaboride or barium mixed oxide) or a cold emitter. If the cathode 21/22 comprises a cold emitter, it can contain e.g. metal tips and/or graphite tips and/or carbon nano tubes. Through this configuration, the cathode 21/22 acts as the transmission cathode 21/22 for the γ-radiation. As mentioned, the substrate, such as e.g. Be (beryllium), Al (aluminum) or graphite, in particular pyrolytic graphite, is preferably as transparent as possible for X-ray radiation γ.

According to the invention, the vacuumized internal chamber 41/42 of the X-ray tube 11/12 can be closed off by the transmission cathode 31/32 toward the outside, or respectively toward the inside, for example. The radiation goes through the transmission cathode 21/22, and behind it hits the material to be irradiated. The anode 31/32 comprises a layer of a metal with a high atomic number, e.g. gold and/or molybdenum and/or tungsten and/or a compound of the metals, allowing an efficient conversion into X-ray radiation γ. The anode 31/32 further comprises a cooling for cooling the thermal energy being created. The anode 31/32 must be cooled since typically only about 1 % of the electric capacity is converted into X-ray radiation, and the rest must be given off as heat. The cooling can take place using water or with forced air. Through the configuration according to the invention, the entire radiation can be made use of in the outer half space. In contrast, in the conventional configuration, only about 10 % of the radiation can be used in the half space (with 50° angle of opening of the window). A second advantage is that the area irradiated by the electrons e^- is considerably larger in the design according to the invention than in the conventional configuration. Assuming an irradiated area (anode) of 20 x 20 cm^2 and a possible cooling capacity in this area of 200 W/cm^2, there results a possible total electrical power of 80 kW, in contrast to 6 kW with the conventional tube. That is a further increase by a factor of 10. A transmission cathode 21/22 possibly absorbs, however, more radiation than a Be window in a conventional tube, depending upon the design. The output radiation is can <sic.> be thereby reduced by about half, depending upon wavelength. A dose rate increased overall by a factor of 50 still nevertheless results from this on a area of about 20 x 20 cm^2, compared with the configuration with a conventional X-ray emitter. This increase in dosing capacity makes it possible, for example, to carry out sterilization with X rays in very short time periods.

Figure 1 shows schematically an architecture of such a conventional X-ray tube 10 of the state of the art. Electrons e^- are thereby emitted from an electron emitter, i.e. a cathode 20, as a rule a hot tungsten coil, are accelerated to a target through impressed high voltage, X rays γ being emitted from the target, i.e. from the anode 30, through a window 301. In other words, with the impingement of the electrons e^- on the target, X-ray radiation γ is generated at the thus arising focal spot. The X-ray radiation emerges into the outer space

through a window 301, and is used for irradiation purposes. Of the radiation generated on the target, only a small portion reaches the material to be irradiated. For reasons of geometry, the major part of the radiation is absorbed in the tube itself. For this reason, in order to irradiate the object completely, a particular irradiation spacing must be selected, depending upon the size of the object. In conventional configurations, typically, only about 10 % of the radiation can be used in the half space of the target surface. Figure 1 shows an emission window 301 with an opening of 50°.

Figure 2 shows schematically the architecture of one embodiment variant of an X-ray tube 11 according to the invention. Electrons e^- are thereby emitted from a transmission cathode 21, and X rays γ are emitted from an anode 31, the cathode 21 forming the cylinder barrel of a cylindrical tube core, and closing the vacuumized internal chamber 41. In other words, the X-ray tube 11 is designed as anode hollow cylinder 31 with a coaxial cathode hollow cylinder 21 inside. Anode 31 and cathode 21 can be achieved as described in more detail further above, for example. The electrons e^- are accelerated from the transmission cathode 21 to the anode 31, and generate there X-ray radiation γ. The X-ray radiation γ penetrates the cathode 21 transparent for X-ray radiation γ. A uniform and very high 4π- gamma radiation, for example, can thus be achieved inside the cathode hollow cylinder 21. The material to be irradiated can be placed inside the cathode hollow cylinder 31. This ensures an even irradiation of the object from all sides, which would hardly be possible otherwise. This can be especially expedient for sterilization. It can be said that this embodiment variant is particularly suitable for sterilization with continuous conveyance of the material to be sterilized, and thereby for high throughput. A further advantage of this embodiment example is that since the anode does not have to be selected to be transparent for X-ray radiation, the cooling of the anode can be optimized compared with an embodiment variant with an anode transparent for X rays.

Figure 3 shows schematically an architecture of another embodiment example of an X-ray tube 12 according to the invention. Electrons e^- are thereby emitted from thermionic or cold emitters 72 in a transmission cathode 22, and X rays γ are radiated from an anode 32, the cathode 32 closing the

vacuumized internal chamber 42 toward the outside. The cathode 32 is designed as a round or angular surface, the anode 32 being irradiated by the emitters 72 of laminar, reticular or linear design, for example. Like reference numeral 50, reference numeral 52 designates e.g. a metallic cylindrical housing 52, which comprises the vacuumized internal chamber 42, and reference numeral 62 designates an insulator, which separates the potential of the cathode and of the anode. It is also conceivable, however, for the housing 52 to be produced out of an insulating material, and for the insulator 62 to then be omitted. It is to be pointed out that the embodiment variants described by means of Figures 2 and 3 are especially intended for use of cold emitters, through the use of large-surface electron emitter configurations. Configurations with thermal cathodes are of course also conceivable, however.